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A study on nutrient optimization for enhanced geranium oil yield in the lower altitude zones of Uttarakhand, India

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Abstract

This study, carried out at CSIR-Central Institute of Medicinal and Aromatic Plant Research Centre Purara, Bageshwar (Uttarakhand), investigated the growth and productivity of geranium crops under different NPK doses in the lower hills of Uttarakhand. Nine different NPK treatments, varying from 60:40:20 to 220:200:180 kg ha^{-1}, were applied using a Randomised Block Design. Examined factors related to plant growth and yield, included plant height, diameter, stem count, leaf count, fresh shoot biomass per gramme of plant, and fresh herb yield per hectare. The 180:160:140 NPK level produced the highest fresh herb yield of 327.29 q ha^{-1}, which corresponded to the highest oil yield of 163.65 kg ha^{-1}. This study provides valuable insights into optimising NPK formulations to improve geranium crop yields, which is essential for increasing agricultural productivity in the Himalayan hills of Uttarakhand.

Key words: Geranium, *Pelargonium graveolens* L., aromatic, nutrient

Introduction

Geranium (*Pelargonium graveolens* L.), a prized aromatic crop in the Geraniaceae family, is famous for its essential oil, also known as rose geranium due to its strong rosy fragrance (Pandey *et al.*, 2020). Geranium has significant botanical diversity, with approximately 600 species in the *Pelargonium* genus, many of which exude delightful fragrances (Ili *et al.*, 2021). Although species such as P. radula and P. fragrance have lower economic value (Nishida *et al.*, 2020), geranium's native roots can be traced back to South Africa's Cape Province (Esfandani-Bozchaloyi *et al.*, 2018).

This bushy plant grows to 1.3 m in height and has a hairy, cylindrical stem that becomes woody at the base as it matures. Geranium has an umbellate inflorescence with bisexual, hypogenous flowers with violet-pink corollas and alternate, stipulate, and densely pubescent leaves. Geraniums are propagated vegetatively, and their initial slow growth often leaves the land uncovered. This shallow-rooted crop thrives in well-drained porous soil and is highly responsive to high nitrogen doses for increased biomass (Mazeed *et al.*, 2020).

Geranium adapts to temperate, subtropical, and tropical climates and altitudes ranging from 1000 to 2200 m. Temperatures ranging from 23 to 50 ºC are ideal for the crop; temperatures below 30 ºC risk chilling injury, while heavy rainfall and waterlogging can cause root rot. Surprisingly, geranium thrives at lower altitudes and can withstand temperatures as high as 43°C with proper irrigation.

Geranium oil is widely used in cosmetics and perfumery formulations because of its strong fragrance. Its essential oil is used for isolating rhodinal compounds, which are important in high-end perfumes. Major constituents such as citranellol, geraniol, and linalool have muscle relaxant properties, which contribute to skincare products and health remedies such as those used to treat dysentery, inflammation, and even cancer. Notably, Western countries use geranium oil to treat a variety of health issues.

Geranium oil's main components, including geranial and citronellol, among many others, contribute to its unique properties. The essential oil's quality is determined by careful nutrient management and agroclimatic conditions. While globally cultivated, with annual production of 250-300 t, demand exceeds supply by more than 500 t. Geranium oil imports into India exceed 20 t to meet local perfumery needs. Geranium oil is primarily grown in the South Indian plains and commercially cultivated in the Nilgiris, Kodaikanal hills, and Karnataka. Annual geranium oil production in India is approximately 20 t.

This study investigates the potential of geranium crop in the lower hills of Uttarakhand under various fertiliser doses. The goal was to find optimal NPK combinations that not only increase local farm output but also contribute to overall industrial growth in the Himalayan hills.

Materials and methods

The research was conducted during the *Zaid* cropping season of 2021 at CIMAP-RC, Purara, Bageshwar, Uttarakhand, situated at an altitude of 1500-1560 m MSL (29.92°N, 79.62°E). The climate is tropical to subtropical, with summer temperatures ranging from 20 to 30 °C and winter temperatures dropping to a minimum of 0°C. The maximum winter temperature reaches 22°C, and the monsoon typically spans from June to mid-September. Prior to planting, soil samples were collected and analyzed at CSIR-CIMAP Pantnagar. The soil exhibited a pH of 6.94, electrical conductivity of 70.58 µS cm^{-1}, and organic carbon content of 0.87%. Soil nutrient levels were determined as follows: nitrogen 323 kg ha^{-1}, phosphorus 29 kg ha^{-1} and potassium 187.04 kg ha^{-1}.

The experiment followed a Randomized Block Design, with nine NPK treatments (60:40:20, 80:60:40, 100:80:60, 120:100:80, 140:120:100, 160:140:120, 180:160:140, 200:180:160, 220:200:180) replicated thrice. Each experimental plot covered an area of 4.68 m^2, utilizing the CIM-Bourbon variety planted at a spacing of 50 × 50 cm. Fertilizers, including urea, muriate of potash, and single super phosphate, were applied for nitrogen, phosphorus, and potassium, respectively. Nitrogen was administered in three split doses (50, 25 and 25%), with half applied as basal. Regular intercultural activities, such as hoeing, weeding, irrigation, and top dressing of nitrogen, were conducted as required.

Plant growth parameters, including plant height, plant diameter, number of leaves, number of branches, root length, fresh and dry weight of plant biomass, dry weight of herb, fresh yield of herb, oil percentage, and oil yield, were measured. Observations were taken from five random plants in each plot. Plant height and diameter were measured with a meter scale. Geranium oil was extracted using the Clevenger apparatus, and its constituents were analyzed by GLC at CIMAP Pantnagar using a Thermo Fischer Trace GC-1300. Statistical analysis utilized the complete randomized block design, and data analysis was performed using OPSTAT, an online statistical analytical program available at Chaudhary Charan Singh Haryana Agricultural University in Hisar, Haryana, India.

Results and discussion

Impact of nutrients on plant growth at 30 DAT: Field data collected 30 days post-transplantation showed that varying NPK levels had no significant impact on plant height, number of branches, and number of leaves (Table 1). Plant height ranged from 16.67 cm to 17.8 cm, with no clear pattern across treatments. The number of branches fluctuated between 1.5 and 1.8. The highest average number of leaves (33.6) was observed under the NPK level 140:120:100, and the greatest plant diameter (15.07) occurred with the 120:100:80 treatment. The effect of NPK levels on plant diameter was statistically significant, consistent with a prior geranium study (Pandey and Patra, 2015).

At 30 days post-transplantation, no significant differences were found in plant growth parameters across treatments. Although growth increased with nutrient levels, it wasn't remarkable. This aligns with a geranium study showing slow early-stage growth (Prakasa Rao *et al.*, 1984).

Impact of nutrients on plant growth at 60 DAT: Crop data at 60 days post-transplantation indicates a significant impact of different NPK levels on plant height (Table 2). The lowest NPK level 60:40:20 resulted in an average plant height of 30.5 cm, while NPK levels 160:140:120, 180:160:140, 200:180:160, and 220:200:180 had average plant heights of 37 cm, 37.23 cm, 31.03 cm, and 37.9 cm, respectively. The number of branches increased with higher NPK levels, reaching a maximum of 7.33 under NPK 200:180:160. Different NPK levels significantly influenced the average number of branches. The highest average number of leaves, 78.93, was observed under treatment 160:140:120,

Table 1. Effect of NPK doses on plant growth characteristics at 30 DAT

Treatments	Plant height (cm)	Number of branches	Number of leaves	Plant diameter (cm)
60:40:20	16.67	1.50	22.80	12.93
80:60:40	17.10	1.53	28.27	14.80
100:80:60	17.73	1.53	28.07	13.27
120:100:80	17.80	1.67	28.80	15.07
140:120:100	17.90	1.53	33.60	14.20
160:140:120	16.83	1.80	32.80	13.73
180:160:140	16.87	1.73	32.53	14.93
200:180:160	17.27	1.80	27.90	12.67
220:200:180	17.00	1.60	26.97	13.80
SEM (±)	1.00	0.21	2.59	1.32
SED	1.42	0.30	3.67	1.87
CD (P=0.05)	NS	NS	NS	3.99

whereas the minimum, 62.6, was recorded under treatment 100:80:60. Treatments had a significant effect on the average number of leaves. Maximum plant diameter, recorded under NPK 140:120:100 and 160:140:120, was 41 and 41.07, respectively. The effect of treatments on plant diameter was observed to be significant.

Data at 60 days post-transplantation revealed significant variation in all treatments. From 30 to 60 days post-transplantation, a higher rate of plant growth was recorded. Additionally, plant growth observations were higher in treatments with increased nutrient amounts compared to those with lower nutrient doses. Our findings align with a geranium study conducted in Brazil (Rabelo *et al.*, 2015).

Table 2. Influence of NPK doses on plant growth characteristics at 60 DAT

Treatments	Plant height (cm)	Number of primary branches	Number of leaves	Plant diameter (cm)
60:40:20	30.50	5.47	64.94	32.10
80:60:40	33.13	5.53	68.81	29.07
100:80:60	37.00	5.53	62.60	32.60
120:100:80	34.33	6.60	71.67	38.53
140:120:100	35.93	6.20	70.83	41.00
160:140:120	37.00	6.60	78.93	41.07
180:160:140	37.23	5.67	73.07	40.57
200:180:160	37.03	7.27	72.57	40.47
220:200:180	37.90	7.33	69.41	35.87
SEM (±)	1.39	0.38	1.68	1.93
SED	1.96	0.53	2.37	2.73
CD (P=0.05)	4.20	1.14	5.07	5.84

Impact of nutrients on plant growth at harvesting stage: Field data at harvest stage revealed a significant impact of different NPK levels on plant height, primary branches, and number of leaves (Table 3). The highest plant height, 69.47 cm, was observed under NPK 180:160:140, showing an increasing trend with NPK levels, but a decrease was noted for NPK 200:180:160 and 220:200:180 (68.17 cm and 67.83 cm, respectively). The maximum number of primary branches (7.33) was observed under NPK 220:200:180. The number of leaves increased with NPK levels, reaching a peak under NPK 180:160:140 (311.8), with reductions observed beyond this dose (NPK 200:180:160 and 220:200:180 with 280.73 and 288.83, respectively). The lowest dose (60:40:20) had 166.67 leaves.

The maximum average plant diameter was 42.07 cm under NPK 180:160:140, while the minimum was 33.57 cm under NPK 60:40:20. The effect of different NPK levels on plant diameter was non-significant. The highest average root length was 24.33 cm under NPK 200:180:160, with an insignificant effect of various NPK doses on root length.

NPK dosages played a role in plant morphology, significantly impacting growth characteristics like plant height, number of leaves, leaf width, leaf length, and number of branches. Consistent with our findings, research in Thailand demonstrated the influence of nitrogen on plant growth in Japanese mint (Janpen *et al.*, 2019). In Iraq, the application of NPK fertilizer enhanced herb yield in *Pelargonium graveolens* L'Herit (Hammo and Salyh, 2020). Studies in *Rosmarinus officinalis, lemongrass, Ocimum basilicum* and *Origanum vulgare* indicated increased vegetative growth and development characteristics with higher nitrogen levels (Munnu Singh, 2013; Singh *et al.*, 1996; Abou El Salehein *et al.*, 2021; Nikou *et al.*, 2019).

Table 3. Assessing the effect of NPK doses on plant growth characteristics at harvesting stage

Treatments	Plant height (cm)	Number of primary branches	Number of leaves	Plant diameter (cm)	Root length (cm)
60:40:20	56.00	5.20	166.67	33.57	17.40
80:60:40	63.77	5.23	207.20	36.60	18.13
100:80:60	64.23	5.40	233.67	36.40	18.07
120:100:80	64.83	5.57	269.27	37.70	22.47
140:120:100	65.83	6.53	277.13	38.33	20.63
160:140:120	68.87	6.27	281.30	38.10	20.33
180:160:140	69.47	6.93	311.80	42.07	24.30
200:180:160	68.17	7.27	280.73	40.13	24.33
220:200:180	67.83	7.33	288.83	40.33	18.07
SEM (±)	2.03	0.17	15.26	1.88	1.95
SED	2.87	0.23	21.58	2.66	2.75
CD (P=0.05)	6.13	0.50	46.14	NS	NS

Impact of nutrients on herb and oil yield at harvesting stage: Fresh shoot weight per plant increased with rising NPK levels (Table 4), reaching a minimum of 355.97 g plant^{-1} under NPK 60:40:20 and a maximum of 818.23 g plant^{-1} under NPK 180:140:140. However, further increases in fertilizer doses (NPK 200:180:160 and 220:200:180) did not elevate the fresh shoot weight significantly (783.8 and 795.93 g plant^{-1}, respectively). Various NPK doses had a significant effect on fresh shoot weight.

The highest fresh root weight per plant was observed under NPK 180:160:140 (20.97 g plant^{-1}), indicating a significant impact of different NPK levels on fresh root weight. Dry shoot weight per plant was also highest under NPK 180:160:140 (149 g), while the minimum was 72.9 g under NPK 60:40:20. Various NPK doses significantly affected this factor.

Fresh herb yield per hectare was highest under NPK 180:160:140 (327.29 q ha^{-1}), but further application of fertilizers led to decreased yields (313.52 q ha^{-1} and 318 q ha^{-1} for NPK 200:180:160 and 220:200:180, respectively). NPK 60:40:20 yielded 142.39 q ha^{-1}. Initially, the fresh herb yield increased up to NPK 180:160:140, but on further application, the yield lessened. Various NPK levels significantly affected fresh herb yield.

The oil percentage in geranium biomass varied from 0.3% to 0.5%, with the highest (0.5%) under NPK 180:160:140. Various NPK levels had a significant effect on oil percentage. The oil yield was highest under NPK 180:160:140 (163.65 kg ha^{-1}), while the least was under NPK 60:40:20 (42.72 kg ha^{-1}). NPK 200:180:160 and 220:200:180 produced oil yields of 125.41 and 127.35 kg ha^{-1}, respectively. Different fertilizer doses significantly affected oil yield.

The study indicated that well-developed nutrient treatments led to higher plant growth and better herb and oil yields. These findings align with studies on celery, chrysanthemum, *Artemisia annua* Linn, *Stevia rebaudiana*, and rice. The yield of oil is influenced by both plant growth and herb yield. Plants provided with more nutrients exhibited higher vegetative and oil yields, particularly influenced by nitrogen. This positive trend of oil with nitrogen application is consistent with previous findings on bergamot mint and mint crops.

Table 4. Effect of NPK doses on herb and oil yield

Treatments	Fresh shoot weight (g plant^{-1})	Fresh root weight (g plant^{-1})	Dry shoot weight (g plant^{-1})	Fresh herb yield (q ha^{-1})	Oil %	Oil yield (kg ha^{-1})
60:40:20	355.97	8.63	72.90	142.39	0.30	42.72
80:60:40	472.97	13.07	93.77	189.19	0.40	75.67
100:80:60	544.93	16.29	114.77	217.97	0.40	87.19
120:100:80	619.80	18.33	137.97	247.92	0.40	99.17
140:120:100	688.60	19.73	134.47	275.44	0.40	110.18
160:140:120	752.73	19.30	141.50	301.09	0.40	120.44
180:160:140	818.23	20.97	149.00	327.29	0.50	163.65
200:180:160	783.80	18.33	137.27	313.52	0.40	125.41
220:200:180	795.93	18.47	141.93	318.37	0.40	127.35
SEM (±)	9.29	0.86	3.95	3.72	0.00	1.56
SED	13.14	1.22	5.58	5.26	0.00	2.21
CD (P=0.05)	28.10	2.60	11.94	11.24	0.008	4.72

Impact on nutrients on biochemical constituents of geranium essential oil: Geranium essential oil quality analysis revealed geraniol and citronellol as the major constituents (Table 5). The highest geraniol content was under NPK 80:60:40 (29.3%), followed by NPK 60:40:20 (27.5%). As NPK levels increased, geraniol content decreased, reaching a minimum of 21.8% under NPK 160:140:120, and ranged from 24.3 to 24.7% in NPK levels 180:160:140, 200:180:160, and 220:200:180. Citronellol content varied from 23 to 26.1%, peaking at 26.1% under NPK 200:180:160. Other compounds included linalool (4.2 to 6.7%, highest at NPK 100:80:60), isomenthone (6 to 6.7%, highest at NPK 200:180:160), citronellyl acetate (7.3 to 8.6%, highest at NPK 100:80:60), neral (constant at 0.7%), geranyl formate (3.5 to 4.3%), and 10-epi-γ-eudesmol (6.6 to 8.1%, highest at NPK 100:80:60).

Minor constituents included α-pinene, β-pinene, limonene, menthone, citronellyl acetate, geranyl acetate, β-caryophyllene, germacrene-D, cis-β-guaiene, 2-phenyl ethyl tiglate, geranyl valerate, and geranyl tiglate. The highest overall composition of oil constituents was found under NPK 60:40:20 (93.6%).

Table 5. Influence of NPK doses on biochemical constituents of geranium essential oil

S. No.	Compound name	T1	T2	T3	T4	T5	T6	T7	T8	T9
1.	α-pinene	0.3	0.2	0.2	0.3	0.4	0.3	0.3	0.2	0.2
2.	β-pinene	0.1	0.1	0.1	0.1	0.1	0.1	-	0.1	0.1
3.	Limonene	0.2	0.2	0.1	0.1	0.1	0.3	-	0.1	0.1
4.	Linalool	4.6	5.2	6.7	5.4	5.1	4.2	4.8	5.3	4.5
5.	Menthone	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2
6.	Isomenthone	6.2	6.5	6.0	6.0	6.3	6.4	6.6	6.7	6.6
7.	Citronellol	25.9	23.0	23.7	23.4	23.7	25.9	24.3	26.1	23
8.	Neral	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
9.	Geraniol	27.5	29.3	25.5	25.4	23.9	21.8	24.3	24.8	24.7
10.	Citronellyl acetate	7.8	7.5	8.6	7.3	8.1	8.3	8.1	8.0	7.7
11.	Geranyl formate	4.0	4.1	4.1	3.5	4.3	4.1	4.1	3.8	4.0
12.	Citronellyl acetate	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
13.	Geranyl acetate	0.6	0.6	0.4	0.7	0.7	1.0	0.6	0.8	0.7
14.	β-caryophyllene	0.8	0.6	0.5	0.8	0.8	0.9	0.8	0.9	1.0
15.	Germacrene-D	1.6	1.2	0.8	1.3	1.8	1.6	1.6	2.0	1.7
16.	Cis-β-Guaiene	1.4	1.1	0.8	1.4	1.4	1.3	1.3	1.4	1.5
17.	2-phenyl ethyl tiglate	1.0	1.0	1.3	1.1	1.1	1.2	1.3	1.0	1.1
18.	10-epi-γ-eudesmol	7.0	6.7	8.1	7.3	6.8	7.2	7.7	6.6	7.9
19.	Geranyl valerate	1.1	1.6	2.2	1.9	1.5	1.6	1.8	1.5	1.9
20.	Geranyl tiglate	2.4	2.3	2.5	2.7	2.9	2.5	2.5	2.5	2.9
21.	Total composition	93.6	92.3	92.6	89.8	90.1	89.8	91.2	92.9	90.7

A study on nitrogen's effect on geranium oil quality found that increased nitrogen intake raised citronellol levels, particularly in autumn. While this may enhance certain qualities, it could counteract the benefits of increased yield with higher nitrogen application in specific commercial applications (Araya *et al.*, 2006).

Our study examined how NPK levels affected geranium plant growth, yield, and biochemical constituents at different stages. No significant effect was seen on plant height, branches, or leaves 30 days post-transplantation. Under 140:120:100 NPK, leaves and plant diameter averaged the most. At 60 days post-transplantation, NPK levels significantly affected plant height, branches, leaves, and diameter, showing a positive relationship between nutrients and plant growth. Harvest stage data confirmed that NPK levels affect plant height, primary branches, leaves, and diameter, demonstrating that nutrients shape plant morphology. The subsequent herb and oil yield analysis showed that well-developed nutrient treatments increase yields. The biochemical analysis of geranium essential oil showed different concentrations of major constituents at different NPK levels, emphasising the complex relationship between nutrient supply and oil composition. Our findings support previous research and emphasise the importance of tailored nutrient management for geranium growth and essential oil quality.

Conflict of interests: The authors have not declared any conflict of interests.

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